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Using UHF proximity loggers to quantify male–female interactions: A scoping study of estrous activity in cattle

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ABSTRACT

Reproductive efficiency is an important determinant of profitable cattle breeding systems and the success of assisted reproductive techniques (ART) in wildlife conservation programs. Methods of estrous detection used in intensive beef and dairy cattle systems lack accuracy and remain the single biggest issue for improvement of reproductive rates and such methods are not practical for either large-scale extensive beef cattle enterprises or free-living mammalian species. Recent developments in UHF (ultra high frequency) proximity logger telemetry devices have been used to provide a continuous pair-wise measure of associations between individual animals for both livestock and wildlife. The objective of this study was to explore the potential of using UHF telemetry to identify the reproductive cycle phenotype in terms of intensity and duration of estrus. The study was conducted using Belmont Red (interbred Africander Brahman Hereford–Shorthorn) cattle grazing irrigated pasture on Belmont Research Station, northeastern Australia. The cow-bull associations from three groups of cows each with one bull were recorded over a 7-week breeding season and the stage of estrus was identified using ultrasonography. Telemetry data from bull and cows, collected over 4 8-day logger deployments, were log transformed and analyzed by ANOVA. Both the number and duration of bull-cow affiliations were significantly ($P < 0.001$) greater in estrous cows compared to anestrus cows. These results support the development of the UHF technology as a hands-off and noninvasive means of gathering socio-sexual information on both wildlife and livestock for reproductive management.

1. Introduction

Reproductive efficiency is an important determinant of profitability in both the dairy and beef industries (Royal et al., 2000; Burns et al., 2010). Moreover, the lack of basic reproductive data is a major impediment to the successful implementation of conservation programs for endangered mammalian species (Andrabi and Maxwell, 2007). The challenge in rangeland cattle breeding operations is to assess reproductive capacity on cattle rarely handled and in remote locations. In contrast to extensive cattle systems, the intensive cattle industry possesses a range of techniques to monitor a cow's reproductive status. In intensive systems, cow-mounting behavior during sexually active group (SAG) formation, increased activity, assays of milk progesterone, vasectomized bulls and either electronic or

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non-electronic estrous detection aids have been used to detect estrous in cattle (Diskin and Sreenan, 2000; Firk et al., 2002). However, despite the opportunity to monitor cows more intensively in such systems the incidence of silent ovulation is significant (Ranasinghe et al., 2010) and undetected estrus is increasing (Dobson et al., 2008; Walsh et al., 2011).

The issue of poor estrous detection is compounded by the low heritability of traits currently used to genetically improve fertility (Cammack et al., 2009; Burns et al., 2010), but the relatively high heritability of endocrine fertility traits suggests their inclusion in a selection index to improve fertility (Royal et al., 2002). Hence, the accurate identification of the reproductive phenotype in cattle will benefit both genetic and ART strategies that aim to improve reproductive efficiency (Cushman et al., 2007). Genomic studies of estrous expression in dairy cows (Boer et al., 2010; Homer et al., 2013) have identified alleles associated with increased estrous activity which suggests not only potential genetic markers to improve reproduction of cattle, but also expanding studies of the nexus between increasing milk production with traits indicating a decline in both health and fertility of dairy cows (Rauw et al., 1998; Lucy, 2001). Given the between and within breed variation in estrous intensity and duration, a quantitative genetic and genomic investigation of the two traits is warranted. *Bos indicus* cattle evolved in tropical regions and compared to *B. taurus*, have relatively lower reproductive rates (Frisch et al., 1987), inherently less estrous expression (Orihuela, 2000) and lower bull libido (Galina et al., 2007). Nevertheless, breeders of *B. taurus* beef cattle must also ensure that selection for production traits (e.g. steer growth rates and carcass and meat quality) do not compromise either behavioral estrus or pregnancy traits of beef cows (McClure et al., 2010). Estrous detection is of particular concern in the dairy industry where the declining reproductive rates have been associated with a reduction in estrous expression (Dobson et al., 2008; van Eerdenburg, 2008; Walsh et al., 2011); namely, estrous intensity and duration (Cutullic et al., 2009).

However, in terms of male-female reproductive interactions in cattle, we have at one extreme competition between bulls in a multi-sire rangeland beef production system and to the other, artificial insemination (AI) programs in an intensive dairy production system. The latter system dictates that females have no contact with males and therefore no opportunities for any positive biostimulation affect from males (Zalesky et al., 1984; Fiol et al., 2010).

In production systems that include bulls running with cows, a mating event will involve a close encounter between a bull and a cow. Biotelemetry data from UHF transceiver devices (contact or proximity loggers) recording the frequency and duration of close encounters between cows and calves have been used to identify maternal association in free ranging beef cattle (Swain and Bishop-Hurley, 2007). For cattle breeding programs the identification of close encounters during estrous events could be used to determine the reproductive performance of individual animals.

This paper explores whether UHF telemetry that record the frequency and duration of close (<5 m) bull-cow interactions during a 7-week breeding period, can be used to identify estrus. The proximity logger data were tested against data collected from both ovarian and uterine ultrasonography using cattle in an intensive tropical beef grazing system. UHF telemetry as a means to elucidate issues associated with male–female reproductive behavior is discussed.

2. Materials and methods

2.1. Study site and animals

The study was conducted during the 2005–2006 breeding season at Belmont Research Station, a 3260 ha property located in northeastern Australia (150°13′ E, 23°8′ S). Forty-five, 4- to 12-year old Belmont Red (interbred Africander, Brahman and Hereford-Shorthorn – *B. taurus x B. indicus*) lactating cows with their calf-at-foot were allocated to one of three adjacent 7 ha paddocks so in each paddock there was a similar cow age structure. A 5-year old Belmont Red bull was placed in each paddock for the duration of the breeding season: 12 December 2005–27 January 2006. The breeding season on the Belmont Research Station would routinely commence on or about this day in December, continue for 12 weeks with a corresponding peak in the calving season late October to early November. However the bulls in the present study joined their mating families on this date, but were removed after 47 days, coinciding with the end of the study. Once allocated to their paddock the bulls and cows remained in that paddock for the duration of the breeding season. It was assumed that each bull responded normally to cow estrous signals as the bulls had successfully performed in previous breeding seasons. The forage was irrigated Rhodes grass (*Chloris gayana*) and each paddock contained shade trees. The cattle had ad libitum access to water supplied via a water trough. Ethics approval was obtained from the Rockhampton animal ethics committee: RH209/05.

2.2. Deployment of proximity loggers

Proximity loggers (model E2C 181C Sirtrack Ltd., Havelock North, New Zealand) recorded contact between animals by the transmission/reception of UHF signals (Prange et al., 2006). Proximity loggers simultaneously transmit signals to, and receive signals from, other proximity loggers within a predetermined read-range, which was set to a maximum of 5 m in this experiment. The exact distance between those contacts logged will vary since radio waves can be reflected or blocked by objects such as other cows. However, an interaction that is recorded between two individuals that are within 5 m represents a close encounter. A more detailed explanation of the operation of the proximity loggers used in this experiment can be found in Swain and Bishop-Hurley (2007).

As with Prange et al. (2006) we also used a prototype logger and were concerned with relatively limited data storage capacity (memory capacity of 16,384 records) of the logger during periods of peak animal–animal contact activity such as SAG formation. Hence, proximity loggers were deployed on cows, calves and bulls for 1 week, for 4 deployments, with a 1-week gap between. The 1-week gap allowed the collars to be removed and the data downloaded ensuring data were not lost due to the device being at full data capacity. The 1-week delay before the next deployment also allowed routine maintenance of the devices, namely repair of a battery wire prone to breaking causing a loss of data. Both technical issues have been addressed in later versions of the logger.

On day 1 of a deployment, the cows and calves were brought into the yards and randomly allocated to proximity loggers. The proximity logger collars were fitted to the neck of the animal and the group of 15 cows with their calves was taken to their assigned paddock. There were no cases of animals displaying discomfort to the collar. On day 8 of the deployment the animals were brought back to the yards for collar removal and then returned to their assigned paddock. The telemetry data were downloaded from the proximity loggers and the proximity loggers reset for the next deployment. Eight days after collar removal the animals returned to the yards for the random reallocation of the proximity loggers for the next deployment. The dates of the deployments were: (1) 9 December–16 December 2005; (2) 23 December–30 December 2005; (3) 6 January–13 January 2006 and (4) 20 January–27 January 2006. Bulls were fitted with a proximity logger and taken to their paddock during the first deployment of proximity loggers and became part of the reallocation of proximity loggers at subsequent deployments.

2.3. Ultrasound scanning

Estrus was assessed in cows by ovarian ultrasound using a Real Time Ultrasound (Honda HS2000V, HLV-457M probe Tokyo, Japan) with a variable-frequency transducer set at 10 MHz. Scans were conducted by an experienced ultrasonographer at the start and end of each weekly proximity logger deployment. More frequent scanning would have better aligned estrous status with the corresponding telemetry data (i.e. less dilution of the telemetry data for analysis), but for rangeland cows not used to regular mustering this would have increased disruption to the established social, grazing, suckling and SAG formation within the mating family, and may contribute to increased levels of stress, which can detrimental to reproductive behavior as shown by von Borell et al. (2007). At scanning, each ovary was viewed by ultrasound imaging and the presence of a *corpus luteum* (CL) or the diameter (mm) of the largest follicle was recorded. The presence of a CL and the changes in follicular measurements between scans were used to estimate time of estrus. The same ultrasound device was used to determine the pregnancy status (either pregnant or non-pregnant) of the cow and estimate the age and date of conception by measuring crown to rump length of the fetus.

2.4. Ovarian and conception scan class

The ovarian ultrasonography data for each cow for the weekly proximity logger deployment, in combination with a uterine scan (10 February 2006), were used by the ultrasonographer to identify a cow's estrous and pregnancy status for the week the collars were deployed namely: (1) non-pregnant and anestrus/anovulatory; (2) pregnant–diestrus with pregnancy confirmed with uterine scan; (3) estrus–follicular growth, maturation, ovulation and conception confirmed with uterine scan and (4) estrus–follicular growth, maturation, ovulation but no conception.

2.5. Telemetry data processing

Of the 192 proximity logger deployments on the cows and bulls, there were 23 occasions the cow proximity loggers failed to record data for a period of time. However, bull-cow interactions were recorded on both the bull and the cow proximity loggers and reciprocal data from two proximity loggers can be used to determine an association, even when one of the loggers fails to record data (Swain and Bishop-Hurley, 2007). The collar fitted to one of three bulls (Bull B) was lost at the start of the second deployment; thus, there were no telemetry data from this bull during this deployment (treated as missing values). The deployment of proximity loggers coincided with the ovarian scanning schedule of the cows (supplementary Table S1).

2.6. Statistical analyses

Daily contact frequency and contact duration were calculated for each deployment and assigned to one of the four weekly ovarian/conception classes, namely: (1) non-pregnant and anestrus/anovulatory; (2) pregnant; (3) estrus with conception and (4) estrus without conception. As with a previous analysis of telemetry records (Swain and Bishop-Hurley, 2007), the data were log transformed prior to analysis due to large differences in variance. The data were analyzed by ANOVA using GenStat Release 8.1 (Payne et al., 2005) and ovarian-conception class were regarded as fixed effects. As our focus was to document the contact data generated from UHF telemetry during an estrous event in a standard breeding season, the three bulls were not rotated between paddocks. Again, to minimize disruption to estrous events, the mating family remained in their assigned area for grazing for the duration of the breeding season. Hence, we make no statistical inference as to differences in animal reproductive efficiency, libido and paddock affects.

3. Results

It was assumed that the ultrasound was able to indicate the event of estrus and of conception for allocation of cows to the respective classes. The data shown in Supplementary Table S1 is of a cow that conceived on 15 December 2005 during deployment 1 and the conception coincided with 343 bull contacts with a total duration of contacts of 11,734 s on that day. This represents a 17-fold increase in contacts and a 43-fold increase in duration of contacts over the mean number and duration of cow-bull contacts on a daily basis during deployment 2 (19.8 ± 6.06 and 271.5 ± 108.96 s respectively) when the cow was pregnant.

Table 1
Least squares means Log_{10} ($\pm SE_m$) of number and duration of hourly bull-cow contacts for each ovarian/conception class within each deployment.

Ovarian/conception scan class	Number of contacts per h	Duration of contacts per h (s)
Anestrus/anovulatory – non-pregnant	−0.21 ± 0.047^a (0.62)[A]	1.11 ± 0.080^a (12.8)
Diestrus – pregnant	−0.25 ± 0.063^a (0.56)	1.03 ± 0.107^a (10.8)
Estrus – conception	0.16 ± 0.066^b (1.45)	1.69 ± 0.113^b (49.1)
Estrus – but no conception	0.18 ± 0.083^b (1.51)	1.57 ± 0.141^b (37.3)

[ab] Within a column, values with no common superscript are significantly different ($P<0.001$)
[A] Back-transformed value in parentheses.

Table 2
Number of cows in estrus and the total number of contacts and duration of contacts for each deployment of proximity loggers.

Deployment of proximity loggers	Total number of cows in estrus	Overall number of contacts (per cow per day)	Overall duration of contacts (h) (per cow per day)
1	18 (4)[A]	24.9	0.22
2	18 (10)	29.4	0.33
3	7 (8)	13.1	0.14
4	1 (0)	20.6	0.16

Note: the bulls were taken to their assigned paddock midway through deployment 1.
[A] Number of cows determined to have conceived via ultrasonography of the fetus shown in parentheses.

Based on the ovarian/uterine ultrasound each cow for each deployment was allocated to the appropriate ovarian/conception class. Table 1 shows for each ovarian and conception class the $\log_{10}$ transformed values for the number of bull-cow contacts per hour and the corresponding duration of those contacts per deployment. The bull-cow contacts, both number and duration of contacts, were significantly ($P<0.001$) higher during deployments in which estrus occurred (classes 3 and 4) than in deployments in which there were no estrous events (classes 1 and 2). The contact data clearly separated the estrous from anestrous cows, but there were no significant ($P>0.10$) differences within the estrous from anestrous classes (Table 1). The increase in contact activity as an indication of estrus was also associated with a disproportional increase in the duration of contacts. There were 2–3 times more contacts for estrous cows than non-estrous cows, with contacts being 3–5 times longer (Table 1).

The overall accumulation of conceptions of these cows over the 7-week exposure to bulls was relatively high, with 39 cows or 86.7% of cows conceiving during the season. Ultrasonography established that estrus and conception did not occur uniformly throughout the breeding season, but predominately early in the breeding season; in deployments 1, 2 and 3 (Table 2). The peak in contact activity coincided with the peak in conceptions: 29.4 contacts and an average duration of 0.33 h (20 min) per cow per day with 10 conceptions during deployment 2. In the final deployment (deployment 4) there was only a single estrous event detected and zero conceptions, but with over 20 bull contacts of 0.16 h (10 min) per cow per day (Table 2).

Telemetry data also revealed individual animal variation and probable date of conception. Ultrasonography of two cows (Cows 99–840 and 00–019) determined they cycled and conceived during deployment 2 (23–30 December 2005). The telemetry data suggest the peak in estrus for Cow 99-840 occurred on 26 December (390 contacts with accumulated duration of 11.4 h, over 25 and 26 December 2005), whilst for Cow 00-019 estrus only occupied 1 day (317 contacts with an accumulated duration of 5.4 h, over 25 and 26 December 2005) (Fig. 1).

Although the three mating bulls recorded relatively high accumulative proportion pregnant – 93.3, 80.0 and 86.7% for Bulls A, B and C respectively, there was variation in the duration of contact of individual bulls with cows during the estrous period. Table 3 shows the number of bull-cow contacts for at least one close proximity contact (<5 m) of each cow on each day of the deployment over the 4 deployments. It was only during the deployment with the largest number of conceptions (deployment 2), the bulls made contact with every cow in their group every day of the deployment (data not shown). However, not all bulls maintained this regime throughout the breeding season. On only five occasions did Bull A not have contact with every cow in his group on every day of the deployment, whereas, this occurred on 23, or almost 10% of the occasions for Bull C (Table 3).

4. Discussion

The proximity logger is capable of documenting animal-to-animal interactions associated with both wildlife (Prange et al., 2006) and livestock (Swain and Bishop-Hurley, 2007). We present evidence that the technology was also able to record a change in contact behavior between a bull and a cow signifying the onset of estrus

Table 3
The number of days in which the bull made at least one contact with every cow in the breeding group (as recorded by the proximity logger): potential days for the bull-cow contact and number of occasions in which a cow was missed.

Bull	Possible days for a bull-cow contact to be recorded	Number of occasions there was no close contact
A	279	5 (1.8%)[A]
B	204	14 (6.9%)
C	242	23 (9.5%)

[A] Number of days there was no bull-cow contact as a percentage of the total possible days shown in parentheses.

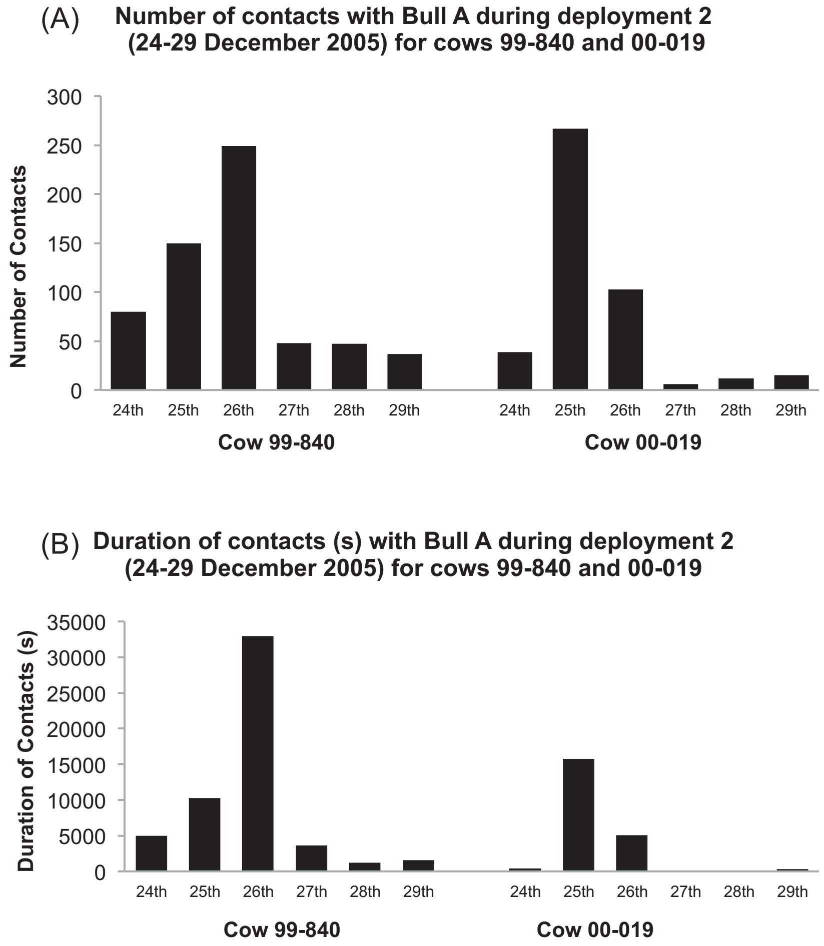

Fig. 1. Daily contacts (A) and duration of contacts (B) of two cows (identities: 99-840 and 00-019) with Bull A where the cows were determined by ultrasonography to be in estrus and have conceived during deployment 2 (23–30 December 2005).

in the cow. Estimates of how often (number of contacts) and for how long (duration of contacts) a bull comes in close proximity (<5 m) with a cow have been presented as reproductive behavior. From these contacts, and in conjunction with ovarian ultrasonography, we are drawing inferences as to the value of the technology in identifying a female's reproductive status (i.e. estrus, anestrus); as an additional aid to the detection of estrus and recording male and female sexual activity. Using UHF proximity loggers to record SAG activity, McNeill et al. (2010) with a threshold algorithm from dairy cow contacts, and O'Neill et al. (2010a) with a Perl program that predicted future estrous events from previous estrous events in beef heifers, concluded the technology was capable of detecting estrus. From our study of bull–cow affiliations we believe the scope for the technology is wider than simple estrous detection and has additional implications for clearly identifying reproductive dysfunction (repeated estrus without conception), male and female libido, relative importance of sociality and of biostimulation in reproductive investment, and the quantification of estrous intensity and duration for both genetic and genomic studies.

The highly significant ($P < 0.001$) elevation in both number and duration of bull-cow contacts associated with the change in follicular measurements of estrous cows (ovarian/conception classes 3 and 4) compared with non-estrous cows (ovarian/conception classes 1 and 2) (Table 1), suggests the technology effectively identified differences in contact activity between estrus and anestrus. The problem of detection of estrus in both *B. indicus* and high milk producing *B. taurus* dairy breeds (Galina and Orihuela, 2007; Roelofs et al., 2010) could be addressed with continued development of UHF telemetry technology alone or in combination with other technologies such as a pedometer (Firk et al., 2002) or a wireless accelerometer and magnetometer system to simultaneously detect estrous and sickness behavior (Pastell et al., 2009; Swain et al., 2011).

Other telemetry systems are used commercially to detect estrus activity (Diskin and Sreenan, 2000), but the essence of the UHF proximity logger is the social context of estrous activity and the ability to separate the components of that activity – each animal's relative contribution to the estrous event. It has long been recognized that there is a social dimension to estrous behavior (Hurnik et al., 1975; Price, 1985), but this area of research remains relatively neglected in both beef (Fordyce et al., 2002; Galina and Orihuela, 2007) and dairy cattle (Ungerfeld, 2007; Walsh et al., 2011). Moreover, a wireless system combining a device (e.g. an accelerometer) to record mounting activity with a UHF telemetry device to record both estrous intensity and duration would provide clarity to the issue of energetic cost and/or negative genetic correlations associated with the reproductive cycle phenotype (Kotiaho, 2001; Blanc et al., 2006). Given that there is no clear cause for the diminished expression of estrus behavior in dairy cattle (van Eerdenburg, 2008; Cornwallis and Uller, 2009) we believe the utilization of UHF biotelemetry to study the social context of the reproduction of all cattle is warranted. Moreover, such a technology would establish relationships within the components of estrous activity (e.g. intensity and duration of sexual contacts). The technology would also enable the investigation of the nexus between reproductive investment and measures of productivity when nutrition is limited (Blanc et al., 2006) as with cows in harsh environments or when the feeding level of the cow falls short of its production potential. Continued development of UHF technology, in combination with other biotelemetry technologies, to generate social, reproductive and sickness behavior information will enable animal breeders to adopt a holistic approach to their animal husbandry.

The overall accumulative proportion pregnant of 86.7% for lactating cows with a 7-week bull exposure was an indication of the herd's relatively high fertility for this region of northern Australia (Burns et al., 2010). That the estrous events and conceptions occurred early in the breeding season rather than throughout the season (Table 2) supports evidence (Burris and Priode, 1958; Frisch et al., 1987; Cushman et al., 2013) of the more reproductive efficient female calving early rather than later in the calving season.

Both the scanning and telemetry data also demonstrated all three bulls were reproductively sound for this breeding season and the blame for any non-pregnant result could be directed at the cow. Indeed, the bulls maintained a presence with the cows throughout the breeding season. The numbers of contacts per cow per day for the first and last deployments were 24.9 and 20.6 respectively, yet the corresponding numbers of cows in estrus were 18 and 1 (Table 3). The bulls did not come in close contact with all of the cows each day, so it is possible that visual and olfactory signals allowed them to detect estrous from a distance. However, the contact activity overall suggests the bulls maintained a sexual vigilance of the cows for signs of estrus and again demonstrated optimal reproductive behavior (Orihuela, 2000).

Cushman et al. (2007) and Cornwallis and Uller (2009) highlight the lack of studies quantifying the relationships between sexual traits. The present study was not designed to identify statistical differences in libido, but to demonstrate the potential role of UHF telemetry in the study of sexual traits and importantly, the interaction between sexual and social traits in mammalian species. The close proximity contacts between bulls and cows noted in this study may not necessarily be extrapolated to other production systems; for example, tropical rangelands or multiple sire breeding programs as with the Fordyce et al. (2002) work. The data showing Bull A failed to make a close contact with every cow on every day on only 1.8% of occasions compared with 9.5% of occasions for Bull C (Table 3), is of little consequence for a production system where the paddocks allocated to the breeding program were only 7 ha in area. The authors make no attempt to draw conclusions as to differences in libido between the three males. Nevertheless, such differences in bull contact activity shown in Table 3 may have consequences if the paddocks assigned to the breeding program are substantially larger and contain competing bulls. Larger paddocks are more representative of rangeland production environments and factors such as the bull's walking ability, olfactory sensors, aggressiveness, sociality and response to female mounting behavior become more prominent for bull performance (Orihuela, 2000; Fordyce et al., 2002).

The data from this study suggest the length of estrous of Cow 99-840 was longer than Cow 00-019 (Fig. 1). Given two other cows from this paddock also conceived during this period (23–30 December 2005), a more conclusive quantification of length of estrus could be based on the contact information of other cows in the group: those cows that form a SAG and especially those that are also in estrus (Phillips and Schofield, 1990). An additional analysis of the interactions between cows might be used to reveal important female–female networks associated with female sociality (Landaeta-Hernández et al., 2002). Ungerfeld (2007) highlighted the lack of information on female-to-female relationship and the need to conduct research as a means of improving the reproductive management of female livestock. While Acevedo et al. (2007) found the most likely cow to be involved in SAG formation was a cow that was in estrus, not all cows respond sexually to the group are in estrus (Phillips and Schofield, 1990). Is it sociality and conforming to group-typical behavior that motivates a non-estrous female to be involved in sexual activity, or is this an indication of high genetic reproductive potential? Proximity loggers may be a useful tool for quantifying which cows participate in SAGs and the duration of the estrous event. However, utilizing data from all cow-cow contacts may not be appropriate for all production systems.

In intensive dairy systems a 'teaser' or vasectomized bull could be incorporated into AI programs (Diskin and Sreenan, 2000) and telemetry records from only bull–cow contacts may be sufficient for estrous detection in this system. Indeed, bulls may use olfactory/gustatory stimuli to predict the onset of estrus several days before the estrous event (French et al., 1989). However, there would need to be screening of such bulls for libido and temperament prior to their use and appropriate supervision once in the herd. Whilst the need for sexual stimulation prior to service has been documented in the bull (Perry and Long, 1992), the role of biostimulation and the impact of the bull's auditory, visual and olfactory stimuli still needs to be clearly defined for the cow (Tauck and Berardinelli, 2007; Ungerfeld, 2007). The positive results from Norton's (2008) Canterbury teaser bull study involving 7 farms and 1528 dairy cows, and the Rekwot et al. (2001) review of pheromones and biostimulation suggests a potential role for utilizing the 'bull effect' in reproductive management of cows in artificial breeding systems. As with the evolutionary consequences for metabolism of dairy cows consuming high-energy diets

(Clauss et al., 2010), there may also be evolutionary consequences for the endocrinology and reproductive signals of dairy females that have gone many generations devoid of male contact and therefore lack of stimulation of male-orientated receptors associated with estrous behavior.

Just as limitations with the satellite-based global positioning systems (GPS) technology have had to be addressed (Hebblewhite and Haydon, 2010; Swain et al., 2011), so to with the emerging UHF technology. Ideally, the UHF biotelemetry should generate data in real-time and at intervals small enough to close the gap between social contacts and the physiological process related to those contacts (Krause et al., 2013). We conclude from the present study that UHF proximity loggers are a viable option for the accurate detection of estrus and there is scope to use the technology to explore socio-sexual signals associated with sexual physiology. However, given the large number of telemetry records generated (1.5 million records in the current study), it is essential the data processing is automated to enable animal breeders to use the information to improve reproduction efficiency. This study required the proximity loggers to be removed after a week of data collection to allow the records to be downloaded. If the proximity logger devices were to be used on commercial cattle or rangeland herbivores an automated wireless data download capability would be required.

For cattle producers, the opportunity then exists for the data from a particular herd to be linked to other herds in a central database for the genetic evaluation of estrous intensity and duration. The quantification of an estrous event has ramifications for improved selection indices for both genetic (Weigel, 2004) and genomic (Homer et al., 2013) options to improve poor reproductive rates in cattle and identification of reproductive dysfunction. Algorithms of UHF telemetry data, combining male–female and female–female contacts, have the potential to not only precisely identify estrous timing, but also quantify the intensity and duration of that estrous event. Such data enables the collection of basic ART data in wildlife species and addressing suboptimal fertility in cattle in a range of production environments. Given the cow's behavioral and physiological response to the production environment is complex (Orihuela, 2000; Ungerfeld, 2007; van Eerdenburg, 2008), data from various telemetry systems (Handcock et al., 2009) have the potential to provide additional information on the reproductive axis in terms of important animal-social-genetic-environment-management interactions (Cornwallis and Uller, 2009; O'Neill et al., 2010b; Walsh et al., 2011).

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.anireprosci.2014.09.017.

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